SEVERE COLD WAVES ON THE TEXAS COAST

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Severe cold waves on the coast of the Gulf of Mexico are infrequent but of great moment. Human habitation and dress are not here adapted to extreme cold; cattle and other livestock are inadequately sheltered from winter extremes, and tropical fruits and winter truck are subject to extensive damage and occasional total destruction from abnormally low temperatures. In economic loss and human suffering, a severe cold wave, reaching our southern and southeastern borders, ranks with the hurricane.

Bennett (1) and Mitchell (2) have treated of cold waves in Florida briefly. The former, as a result of a study of 51 occurrences of freezing temperature at Tampa, has noted the distribution of barometric pressure necessary for extreme cold in that section. Cox (3) has discussed cold waves in the United States and has presented a number of precepts for forecasting their movements. Garriott (4) assembled numerous maps typifying cold-wave conditions and added a discussion, chiefly historical. His collection of maps forms a valuable reference background for any cold wave study.

Aside from these, there have been numerous notes, mostly reviews of individual cold waves. The subject is sufficiently important to merit a more extensive literature. Few explanations have been offered for the failure of numerous intense high-pressure areas to carry the cold to certain sections. Cold-wave warnings, now and then, fail completely of verification and the causes apparently are imperfectly understood. There are so many factors influencing the movement of cold waves and the complexities of the subject seem to be endless.

Cox, in concluding his remarks on cold waves, (3) says:

> It is obvious that the degree of cold recorded in a cold wave depends upon the intensity of cold in the HIGH and the temperature of the LOW in front of the HIGH, the magnitude of the HIGH, the barometric gradient between the HIGH and the LOW and the consequent wind force, the direction of movement of the HIGH and also the LOW or LOWS which it is following, the general character of the sky, the humidity, whether there is snow on the ground, and the season of the year; in a word, all the atmospheric conditions, sometimes even within an area of 3,000 or 4,000 miles or more.

In a treatment of cold waves that have visited the west Gulf coast area, one is concerned with atmospheric conditions over the continent and neighboring oceans. With a full realization of these difficulties, the writer attempts a description of severe cold waves in the area named, with an explanation of some cold-wave failures, together with criteria for forecasting temperature minima. Some of these rules may prove helpful. None is infallible.

Frequency of severe cold waves.—A cold wave in the winter months, in the coast section of Texas, is defined by the Weather Bureau as a fall in temperature of 16° in a 36-hour period to a minimum of 32°. The severe cold waves discussed in the following have all far exceeded these limits both in rapidity of fall and in intensity of cold. Just what degree constitutes a severe cold wave is difficult to determine, but for the purposes of this paper, a fall of 20° to a reading below 25° is considered severe and a fall of 30° or more to a minimum below 20° is considered very severe.

In the 57 years of record at Galveston, 1871 to 1927, inclusive, there have been 27 cold waves with temperature below 25°. These include the cold wave of January, 1928, which set in on December 31, 1927, and reached a minimum of 20° on January 2. Also included as separate cold waves, are those of 1886, 1887 and 1895, which came in pairs with short intermissions. Strictly, there were only 23 instances, as shown in Table 1. In seven, the temperature fell below 20°, counting the pair in 1895 as a single occurrence.

TABLE 1 [1]

Year	Central date of cold wave	Temperature, minimum	Year	Central date of cold wave	Temperature, minimum
		°F.			°F.
1873	Jan. 29	21	1894	Jan. 25	24
1875	Jan. 10	24	1894	Dec. 28	21
1879	Jan. 6	23	1895	Feb. 8	15
1879	Dec. 26	24		Feb. 16	19
1880	Dec. 29	18	1897	Jan. 27	21
1883	Jan. 21	20	1899	Feb. 12	8
1884	Jan. 7	22	1903	Feb. 17	24
1885	Jan. 17	23	1905	Feb. 13	17
1886	Jan. 8	11	1910	Feb. 18	24
	Jan. 12	21	1911	Jan. 3	19
1887	Jan. 3	24	1912	Jan. 12	20
	Jan. 10	24	1918	Jan. 11	16
1888	Jan. 16	23	1928	Jan. 2	20

[1] Dates of cold waves with minima below 25° at Galveston during years 1871 to 1927, inclusive. The first three in parentheses were in reality continuations of the preceding waves and were of little importance. The last occurred in 1928, but the cold set in at the close of 1927.

In some of these cold waves the temperature remained below the limits shown for more than one day. The number of days with temperatures below certain limits is shown in Table 2. For years prior to 1875 there are no records of daily minima.

TABLE 2 [1]

(1)	(2)	(3)	(1)	(2)	(3)
32	177	3.34	20	12	.23
31	153	2.89	19	10	.19
30	120	2.26	18	9	.17
29	102	1.92	17	7	.13
28	77	1.45	16	5	.09
27	66	1.25	15	3	.06
26	54	1.02	14	3	.06
25	38	.72	13	3	.06
24	27	.51	12	3	.06
23	22	.42	11	2	.04
22	18	.34	10	1	.02
21	15	.28	9	1	.02

[1] (1) Temperature limit. (2) Number of days in period 1875 to 1927, inclusive, with temperature *below* degree shown in (1). Months of December, January and February only considered in this table. (3) Average annual number based on this 53-year record.

Probable minima in certain periods have been computed from Marvin's formula for standard deviation and the average interval curve of Spillman, Tolley and Reed (5). The results are shown in Table 3. The actual intervals as averaged from Galveston's record are also given. The frequency of low temperatures is somewhat greater than indicated by the theory of probability. With lower temperatures the discrepancy increases. This is evidently due to slight lack of symmetry in the frequency distribution. Departures below the mean are fewer and of greater average magnitude than those above the mean. Both by experience and the theory of probability based on that experience, the frequency of years with minima below 20° is about one in eight, roughly.

TABLE 3 [1]

(1)	(2)	(3)	(1)	(2)	(3)
5	20.9	5.7	50	13.5	28.0
10	18.2	9.3	100	11.8	28.0
25	15.4	18.7	150	10.9	56.0

[1] (1) Interval in years. (2) Probable minimum in interval shown at left computed from standard deviation and average interval curve. (3) Actual average intervals between occurrences of minima shown in column (2). Record, 56 years at Galveston, Tex.

The frequency of cold waves with temperatures below 25 is slightly greater at Corpus Christi than at Brownsville. The lowest temperature in all cold waves with readings below 25° at either Corpus Christi or Brownsville is given in Table 4. Extremely low temperatures have not been so frequent on the south Texas coast as at Galveston. The temperatures marked with an asterisk in the table are in doubt, but it seems quite probable that the temperature in both instances fell below 25° at Brownsville.

TABLE 4 [1]

Year	Brownsville minimum and date	Corpus Christi minimum and date	Galveston minimum and date
1880	18 Dec. 30	(2)	18 Dec. 29
1886	22 Jan. 9	(2)	11 Jan. 8
1887	26 Dec. 22	24 Dec. 22	29 Dec. 22
1888	21 Jan. 16	16 Jan. 15	23 Jan. 16
1895	22 Feb. 8	16 Feb. 8	15 Feb. 8
1897	(2)	22 Jan. 27	21 Jan. 27
1899	12 Feb. 13	11 Feb. 12	8 Feb. 12
1901	20* Jan. 1	32 Jan. 1	40 Jan. 3
1901	15* Dec. 15	20 Dec. 15	25 Dec. 15
1905	22 Feb. 13	18 Feb. 13	17 Feb. 13
1909	28 Jan. 12	24 Jan. 12	28 Jan. 12
1911	21 Jan. 4	21 Jan. 3	19 Jan. 3
1912	24 Jan. 13	22 Jan. 13	20 Jan. 12
1917	24 Feb. 2	26 Feb. 2	26 Feb. 2
1917	24 Dec. 30	24 Dec. 30	26 Dec. 30
1918	25 Jan. 11	20 Jan. 12	16 Jan. 11
1919	24 Jan. 4	30 Jan. 4	28 Jan. 4
1924	26 Dec. 21	23 Dec. 20	28 Dec. 20
1925	26 Dec. 28	24 Dec. 28	26 Dec. 28

[1] Temperatures below 25° at Corpus Christi and Brownsville, with dates and minima at Galveston for comparison. All dates of minima below 25° are not given—only the lowest in each cold wave. For Galveston's complete data, see Table 1.
[2] No recrod.

*Temperatures seem too low; see discussion in text.

In several cold waves the temperature has been lower on the south Texas coast than at Galveston and the conditions obtaining in the two cold waves of 1901 were of the character that cause colder weather in the lower Rio Grande Valley than on the east coast. The cold wave moves well southward and eastward before the low-pressure area in the extreme south leaves the vicinity of the Rio Grande Valley, moving eastward, usually with diminishing energy. Northwest winds, clear skies, and lower temperatures prevail in the Rio Grande Valley, while the wind continues to blow from the north and northeast on the east coast with overcast sky. When the southern depression moves eastward and northeastward with marked increase in energy before the cold wave has penetrated far to the southward, as in 1886, 1895, and 1918, it is much colder at Galveston.

The fall in temperature.—From highest temperature on one day to lowest of the following, falls in excess of 50° have not been rare on the Texas coast. When the fall, in a precise span of 24 hours, from any hour to another of the same name, exceeds 40°, the cold wave is uncommonly severe. In January, 1918, at Galveston, the 24-hour fall amounted to 42°. In 12 hours, from 11 p. m. of the 10th to 11 a. m. of the 11th, the temperature fell from 63° to 16°, or 47° in 12 hours, and at the latter hour it is normally warmer in January than at 11 p. m. Ahead of cold waves in extreme southern Texas the temperature sometimes rises almost to midsummer heat. On December 13, 1901, the temperature at Corpus Christi rose to 86° and at 7 a. m. of the following day stood at 36° and on the 15th dropped to 20°. It seems doubtful that the greatest changes in northern latitudes, necessarily taking place at lower temperature levels, can so profoundly affect human comfort.

In January, 1886, at Galveston the temperature fell from a maximum of 65° on one day to a minimum of 11° on the following day, a drop of 54°. Such temperature drops are, however, decidedly unusual. Due to the greater diurnal range in temperature, such marked changes from the high temperature of one day to the low of the next are somewhat more common in the interior.

The cold wave, however, is generally but one single violent fluctuation in the midst of a depression of temperature extending over a period of many days. Its southward sweep is usually facilitated by cold waves of lesser proportions preceding. Figure 1 indicates graphically the average march of temperature during the 15 days preceding and 15 following the date of greatest depression in seven severe cold waves. There is evident a deficiency accumulating irregularly through a period of 15 days and a recovery in the same period from and to temperatures approximately normal. A preliminary drop appears on the fourth and fifth days preceding, about the average interval between low pressure areas.

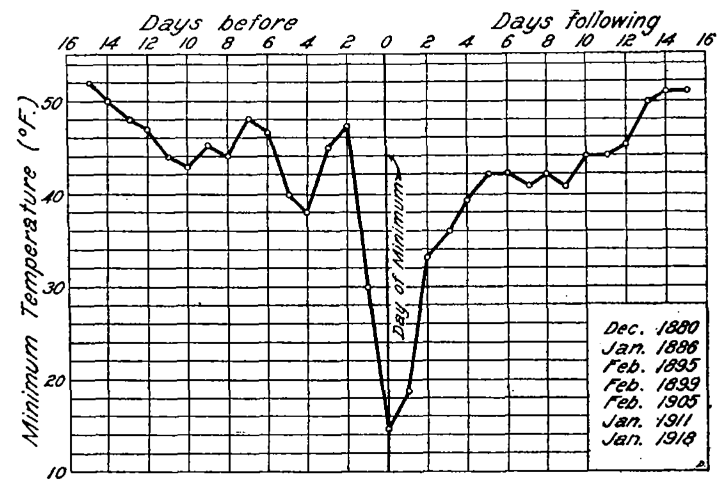

FIG. 1.—Average trend of daily minimum temperatures 15 days preceding and 15 following central date of lowest temperature in seven most severe cold waves at Galveston

The average hourly fall in temperature is shown in Figure 2 for five of the seven severe cold waves. There are no hourly records for the years 1880 and 1886. The minimum is reached in 28 hours after the initial decline. In every instance a temperature within 4° of the minimum was recorded within 30 hours. Counting from the time the temperature begins to fall, it is safe to conclude that only a slightly lower temperature is yet to occur than the minimum of the first 30 hours.

Diurnal variations and the time of day the cold wave arrives are the chief influences in determining the time of occurrence of the minimum. Diurnal effects are exhibited in Figure 3. These are averages of 23 cold waves. Those marked "A" arrived between 6 p. m. and midnight, "B" between noon and 6 p. m., "C" between 6 a. m. and noon and "D" between midnight and 6 a. m. In the two classes arriving before noon of the first day, the minimum occurred on the morning of the second day and in the two classes arriving after noon of the first day the minimum occurred on the morning of the third day. All showed a definite upward trend in the forenoon of the third day. The minimum tended to occur progressively earlier in harmony with the time of arrival but the diurnal change shifted the occurrence to the early morning hours.

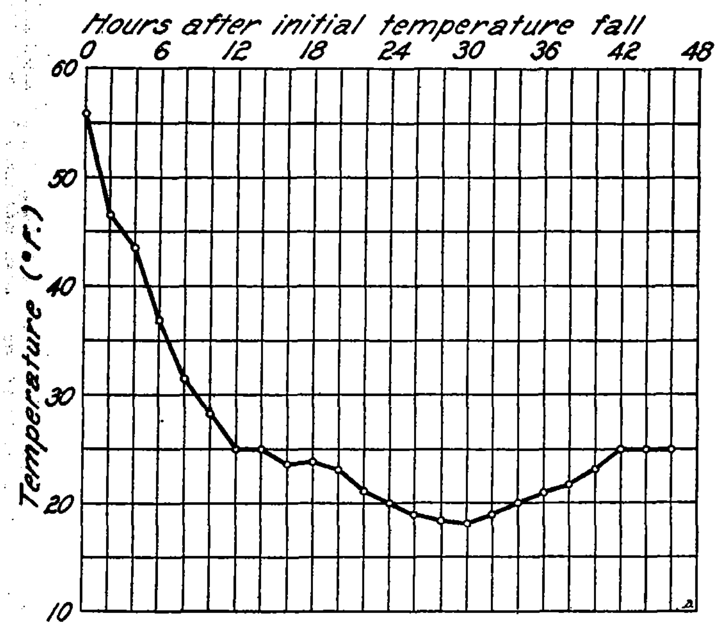

FIG. 2.—Average hourly temperatures in severe cold waves, with minima below 20°, at Galveston. Average temperature at hour of arrival, "0", and each hour thereafter for a total of 48 hours. Average minimum 15°, due to varied interval between arrival and occurrence of minimum temperature, the lowest of the average hourly temperatures is 19°

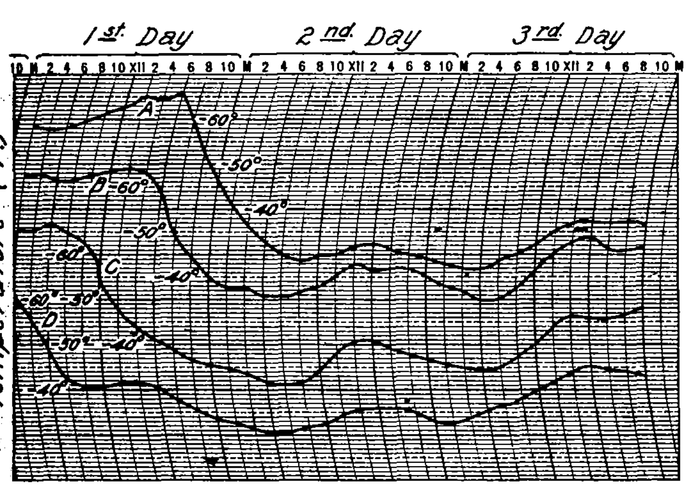

FIG. 3.—Average hourly temperatures in 23 cold waves, 1911 to 1920, inclusive. A, Average for seven cold waves arriving between 6 p. m. and midnight; B, for six cold waves arriving between noon and 6 p. m., C, for six cold waves arriving between 6 a. m. and noon; D, for four cold waves arriving between midnight and 6 a. m.

By averaging the hourly temperatures in the entire group of 23 cold waves, the diurnal variation is largely eliminated and the minimum is found 24 to 30 hours after the initial fall in temperature. This agrees with the findings in the case of the severe cold waves, only two of which are included in the group of 23.

Cloudiness, of course affects the amplitude of the diurnal variation as well as its general character. Differences in the distribution of cloudiness over the State produce peculiar effects. When the weather continues cloudy on the coast but clears in the northern portion of the State the morning minimum is greatly delayed as the cold air from the interior underruns the clouds and its temperature therefore does not rise. In the early night the air from the interior, now warmed by the sun, passes underneath the cloud bank, and, losing little heat through radiation, retards the maximum temperature. It is then sometimes colder at midday than at sunrise and the temperature remains persistently high far into the night. A knowledge of these diurnal influences is essential in order to place accurately the occurrence of minimum temperature.

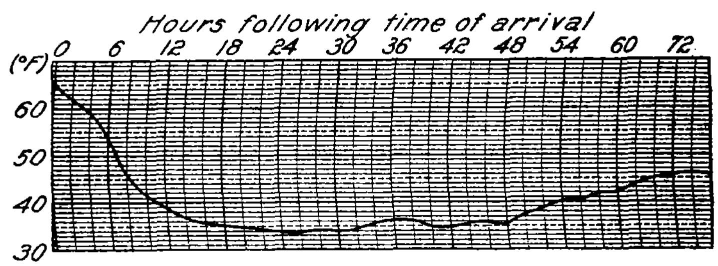

FIG. 4.—Average hourly temperatures in 23 cold waves, 1911 to 1920, inclusive, dating from the hour of initial temperature fall. The time of arrival is "0" hour

Conditions are very favorable when the cold wave arrives early in the day and cloudiness continues until sundown, followed by clearing. In this connection Cox (3) remarks:

> When a cold wave threatens any point, a cloudy sky which prevents the temperature from rising during the day is much more favorable for the verification than when the day is clear, because in that case, the journey to the verifying point will not be so long as if a comparatively high maximum were reached. So also are the chances for verification much better if the ensuing night is clear so that radiation may be free.

Origin of Texas coast cold waves.—The anticyclone bearing winds of the Texas coast cold wave is of the type known as an "Alberta High." It develops over an area embracing the western portion of North Dakota and Montana or, as is more frequently the case, moves in a southerly direction from the British northwest, crossing the Canadian border into that area. The cyclone preceding it develops over Texas, Oklahoma, or northern Mexico or moves through that region from the southern Rockies. Yet it is well known that many strong high-pressure areas have moved into the former area and numerous energetic cyclones have passed through the latter region without producing severe cold waves on the Texas coast. The two, in combination, cause the cold wave, and their movements must be favorably timed. At any stage in the progress of the high and cold wave, there are unfavorable positions for the LOW[1] and, in those situations, the HIGH either blocks the forward movement of the cyclone and the vigorous circulation of the latter opposes the cold winds of the former, or, the cyclone moves too rapidly, drawing the cold to other regions.

When a strong HIGH is advancing into Montana and western North Dakota, a severe cold wave may set in over the Texas coast within 24 hours provided the low-pressure area is favorably situated. It is important, then, that the average movement of southwestern LOWS be accurately known.

According to Bowie and Weightman (6) the average movement in winter is about 750 miles per day. In order that the center of the cyclone may advance far enough to the eastward, in 24 hours, to cause the wind to

[1] The author uses the terms "low" and "cyclone" interchangeably.—*Ed.*

shift on the Texas coast, its position, according to this calculation of average movement, must not be farther west than a line joining Denver, Santa Fe, and El Paso, roughly. In order that its movement may proceed at least at a normal rate, the pressure exerted upon its front must not exceed that upon its rear (7), hence, since its movement must carry it toward the lower Mississippi Valley, the pressure there must not exceed that along a line from Salt Lake City to Modena and along the western border of Arizona.

From a study of the movement of 102 southwestern depressions, the chart shown in Figure 5 has been prepared. Using sea-level pressure at New Orleans as a basis of comparison, the hour lines over southwestern States have been drawn. When the pressure along any of these lines equals the pressure at New Orleans, the wind at Galveston will shift to west or north, in an average case, at the hour indicated on the line.

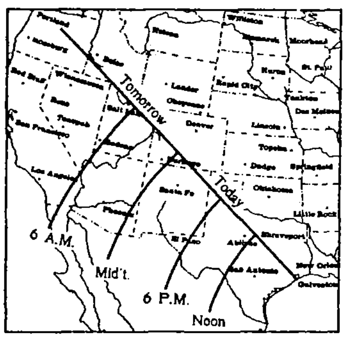

FIG. 5.—When pressures along any line in above chart equal pressure at New Orleans, La., the wind at Galveston will shift to northerly or westerly at hour indicated on line. Low-pressure area must be centered in southern Rockies. When pressure at Helena, Mont., is lower than New Orleans wind will likely shift to southwest or west and when higher to northwest or north

This device has an advantage over the use of the low-pressure center and its average movement, because it takes into account both the location of the center and the pressures exerted upon it.

Pressure indications of severe cold wave.—When the cyclone is over the southern Rockies, pressure must be high in the far Northwest. Relatively low pressure in Montana is at this stage indicative of failure to reach the Texas coast. High pressure in the northern plains normally in 24 hours moves in winter to the upper Mississippi Valley, western Lakes or thereabouts (8). With the crest of the HIGH in the latter region, a cold wave is not likely. The center of the LOW must then be passing through the west Gulf region or the lower Mississippi Valley, unless pressure continues very high in Montana or shows immediate signs of reinforcement.

When a powerful cold wave is sweeping across the Texas coast, a barometric gradient of about 1 inch usually obtains between the northern plains and the lower Mississippi Valley. Great pressure differences between these regions are essential. Therefore, indications must point to a maintenance of high pressure in the northern plains until the LOW in the southern Rockies has moved eastward or southeastward into the lower Mississippi Valley or thereabouts. Any indications of weakening of this pressure in the north before the LOW passes out point to probable failure of the cold wave.

Figure 6 is an isobaric chart, a composite of five, immediately preceding five very severe cold waves reaching the Texas coast, those of 1886, 1895, 1899, 1905, and 1918. Averages of barometric pressures for representative stations, some interpolated from published charts, were used. Approximately 24 hours later, in each instance, a severe cold wave was in progress. The preceding cyclone, having drawn cold air southward and eastward, is evident in the far Northeast. The second cyclone overlies the southern Rockies and a strong high-pressure area is moving southeastward from the British northwest.

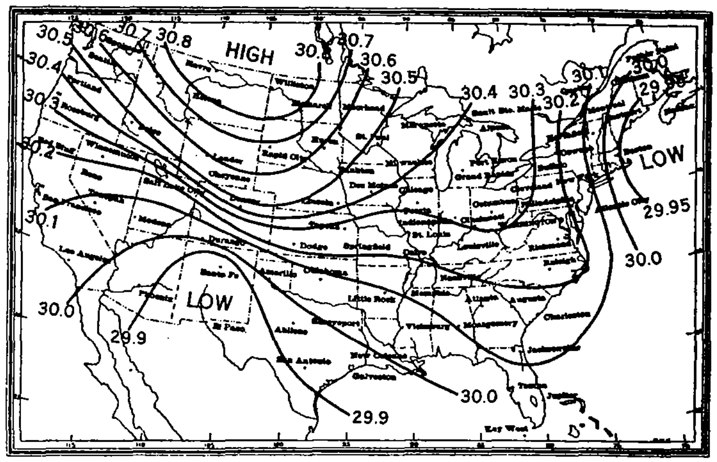

FIG. 6.—Average barometric pressures over the United States, 24 hours, approximately, preceding a severe cold wave on the Texas coast. Composite of five maps—average minimum temperature at Galveston, 13°

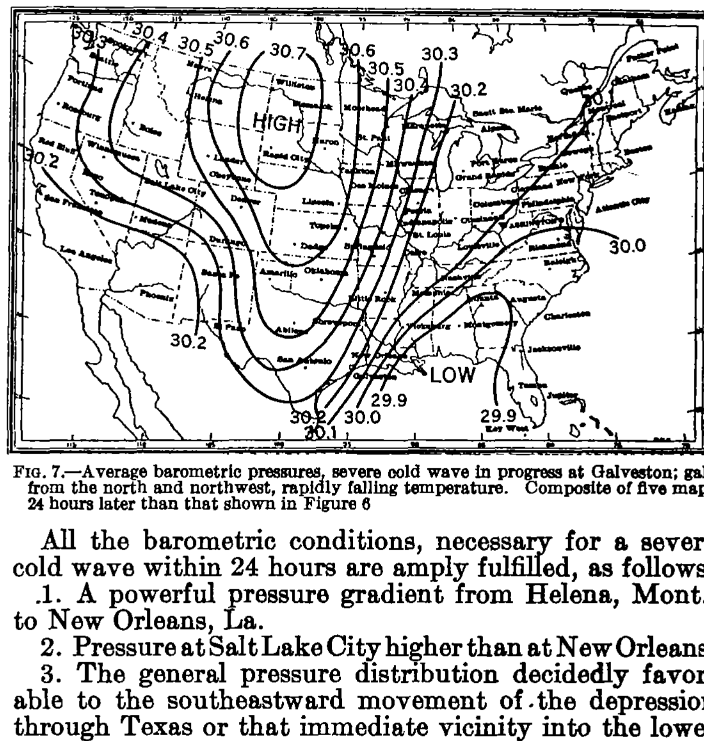

FIG. 7.—Average barometric pressures, severe cold wave in progress at Galveston; gale from the north and northwest, rapidly falling temperature. Composite of five maps 24 hours later than that shown in Figure 6

All the barometric conditions, necessary for a severe cold wave within 24 hours are amply fulfilled, as follows:

1. A powerful pressure gradient from Helena, Mont., to New Orleans, La.
2. Pressure at Salt Lake City higher than at New Orleans.
3. The general pressure distribution decidedly favorable to the southeastward movement of the depression through Texas or that immediate vicinity into the lower Mississippi Valley.
4. Pressure at Helena higher than at Nashville.

Figure 7 is a composite of the five severe cold waves, 24 hours later, with a gale from the northwest, temperature well below freezing and falling rapidly, wind averaging 34 miles at time of observation and a 12-hour maximum averaging 41 miles per hour.

The pressure gradient from North Dakota to southern Louisiana now averages more than 0.80 inch. A powerful indraught of cold takes place through the plains region into West Gulf States. Pressure is relatively high in the Southwest. The crest of the northern HIGH, or center of divergent winds is far to the northward and the cold air is drawn from high latitudes.

From Garriott's collection of cold-wave maps in Bulletin P, (4) I have selected the six cold waves producing the lowest temperatures at Galveston on the following day: December 27, 1894; January 18, 1892; January 23, 1894; February 11, 1894; February 6, 1895; and February 11, 1899. The composite isobaric chart for the six is

Figure 8. The six most conspicuous failures to produce cold waves on the Texas coast on the following day were: December 12, 1893; December 2, 1897; January 3, 1890; December 16, 1897; February 6, 1893; and February 25, 1890. Figure 9 is a composite of these six cold wave maps, the cold failing to reach the Texas coast. In the former the average low temperature of the following day was 20°; in the latter group the low temperature of the following day averaged 52°.

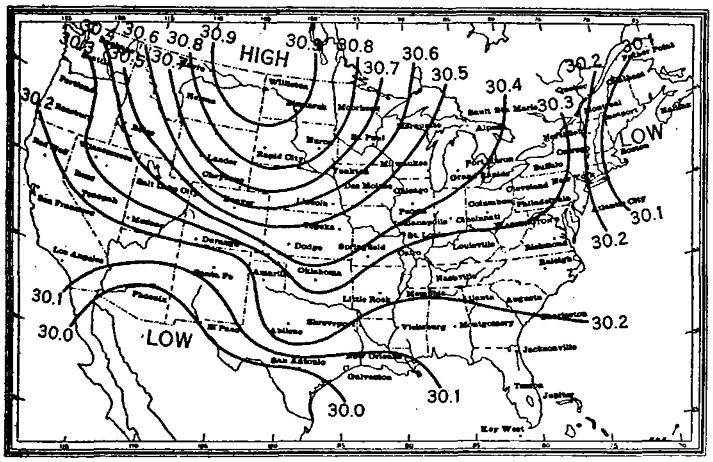

FIG. 8.—Composite map—six severe cold waves in 24 hours at Galveston; from Garriott's collection, Bulletin P

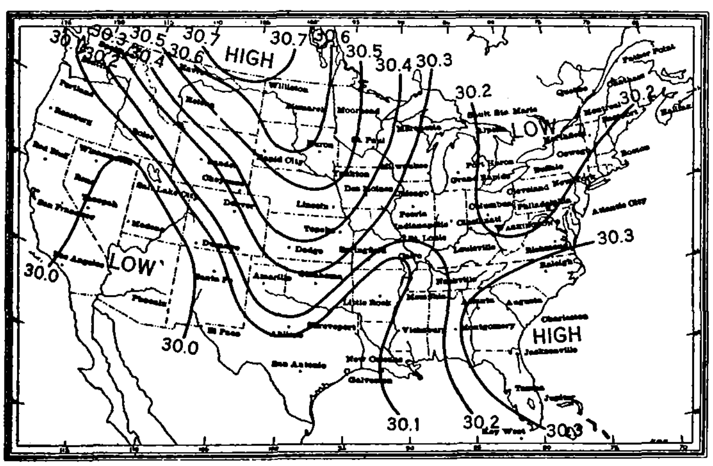

FIG. 9.—Composite of six maps, Garriott's collection; most conspicuous failures to produce cold on Texas coast within 24 hours

In the first series the barometric conditions are fulfilled; in the latter group the gradient, Helena to New Orleans is only about 0.30 inch; the pressure at Salt Lake City is lower than New Orleans, indicating that for nearly 24 hours, at least, the southwestern LOW will oppose the southward advance of the HIGH.

Within 24 hours conditions may change and in some of these instances there was a change with cold weather ultimately reaching the Texas coast. The weather map of the following morning indicates these changes. So far as a severe cold wave is concerned the critical pressure gradient is that from the Rocky Mountain region, Helena, Salt Lake City, and Denver, approximately, on the one hand, and the lower Mississippi Valley on the other.

In short, the cold wave is produced by high pressure and low temperature in the northern plains and low pressure in the lower Mississippi Valley. Preceding this condition by 24 hours, then, the southwestern LOW must be in a position to pass eastward of the Texas coast and pressures exerted upon it must be favorable for such a movement. The barometer must be high *to the westward* of the northern plains region so that high pressure in the latter area will be maintained until the LOW has passed eastward. A well-defined LOW centered in the region about Utah or Nevada is a decidedly unfavorable condition.

It is understood, of course, that barometric tendency at time of report is to be taken into consideration; in all cases the 12-hour pressure changes should be considered.

The minimum temperature forecast.—The minimum reached depends of course on the distribution of temperature over the plains and Rockies as well as barometric pressure and the intensity of indraught of cold from the north. In seeking the most dependable criterion for the temperature forecast, Galveston's resulting temperatures have been compared with those at many places in the southern Rockies and southern plains on the morning of the preceding day. When the major temperature decline has occurred in the southern plains and the cold wave threatens the Texas coast, the minimum of the following morning at Galveston is more closely related to the 7 a. m. temperature, of the previous day, at Oklahoma, than any other place. The mean of the 7 a. m. temperatures at Oklahoma and Santa Fe yields somewhat greater accuracy. Galveston's minimum, under these conditions, averaged 17° higher than the mean of these two stations, on the previous morning.

In any situation which gives assurance of fresh to strong northerly winds over the Texas coast, continuing for 24 hours or more, a forecast on this basis is quite accurate, provided the full force of the cold wave has reached the southern plains.

The cold waves of 1886 and 1895 were almost equally severe. The three were of decidedly similar types. In February, 1899, the coldest weather ever experienced in this area was recorded on the 12th and 13th; the fall in temperature was not so large and the wind movement less violent; temperatures were already below normal over much of the country; and the highest temperature on the 11th at Galveston was 48°.

When exceptionally severe and fast-moving, the cold wave on the first morning had not yet reached the southern plains and Rockies and on the second morning had already swept over the Texas coast. In these cases, and there have been only a few, the temperature at Oklahoma is not by any means a reliable index as to the temperature at Galveston the next morning. The fact is clearly shown, on the weather map, by the crowding of the isotherms between Oklahoma and North Platte.

A composite temperature chart for five of these severe and rapidly moving cold waves is marked "A," Figure 10. Here the difference in temperature between Oklahoma and North Platte was 35°. The average difference between these stations, taken from 51 maps, with a cold wave established over the plains region, was 20°.

Figure 11 is a composite temperature chart for five severe cold waves, already established in the southern plains region. The difference in temperature between Oklahoma and North Platte in these cases averaged 19°. Oklahoma's average temperature was 6° and Galveston's average minimum of the next day, 23°.

In the first instances the temperature fell, during the succeeding 24 hours at Oklahoma, 34° while in the second cases the average fall in the next 24 hours was only 9°. Therefore there was, in the first case, a drop of 25° due at Oklahoma in excess of what would have occurred had the cold wave been well established. Using Oklahoma as an index for the minimum temperature forecast in these cases would have resulted in an average error of 27°, commensurate with the excess fall that took place at that station in the succeeding 24 hours.

Using the night reports, it has long been a precept at the Galveston station that the 7 p. m. temperature at Palestine, Tex., will closely approximate the minimum temperature at Galveston the next morning provided, of course, that the cold wave is in progress and that there are indications that northerly winds will continue through the night. Such a forecast is quite accurate but is not frequently useful.

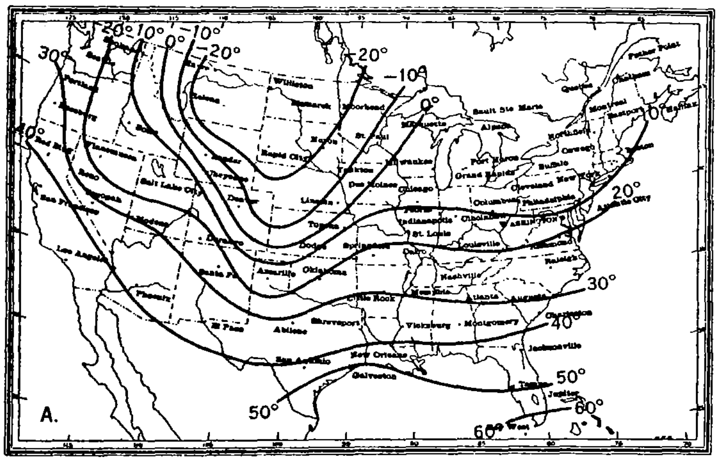

FIG. 10.—Average distribution of temperature 24 hours prior to the five most severe cold waves of record at Galveston. Crowding of isotherms between Oklahoma and North Platte indicates that the full force of the cold wave has not yet reached Oklahoma

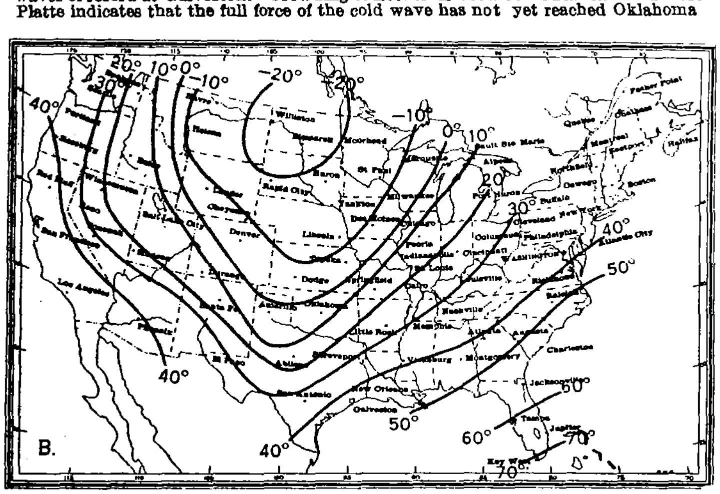

FIG. 11.—Average distribution of temperature approximately 24 hours ahead of five severe cold waves at Galveston, 1892, 1894, 1897, 1911 and 1927. Average minimum at Galveston following day 23°. Cold wave well established over southern plains, indicated by absence of crowding of isotherms between Oklahoma and North Platte apparent in Figure 10

Judged by these standards, the cold wave of January, 1918, was the most violent ever recorded at Galveston. The temperature at Oklahoma on the previous morning was 32°; Galveston's minimum the next day was 16°. The power of the indraught from the north is indicated by the velocity of the wind—56 miles per hour. On the first morning the temperature difference between Oklahoma and North Platte was 38°.

CONCLUSIONS

1. Cold waves with temperatures below 20° occur at Galveston about once in 8 years, at Corpus Christi once in 10 years, at Brownsville once in 15 years; below 25° at Galveston once in 2½ years, at Corpus Christi once in 3 years, at Brownsville once in 3½ years.

2. In cold waves at Galveston a temperature very near the minimum is reached within 30 hours after the initial steep decline begins.

3. When the cold wave arrives before noon, the first day, the minimum occurs generally on the morning of the second day; when it arrives after noon of the first day the minimum is recorded usually the morning of the third day.

4. When clear, the minimum comes shortly after sunrise; when cloudy it is delayed until near noon.

5. Twenty-four hours ahead of the cold wave pressure must be high over Montana and a steep gradient between that locality and the lower Mississippi Valley is essential for a marked fall in temperature. HIGHS with center east of 95° west, and south of 40° north produce little change in temperature.

6. When the LOW is centered in the southern Rockies the time of wind shift on the Texas coast is determined by relative pressures in Utah and southern Louisiana.

Oklahoma seems to be about 24 hours distant in time, judged by the average movement of cold waves.

7. When the HIGH is in the northern plains and pressure is relatively low in the northern Rockies, the depression must be in the west Gulf or lower Mississippi Valley and the cold wave must be in progress on the Texas coast or imminent. Otherwise failure is probable.

8. In any case, a well-defined depression in Utah or Nevada is always indicative of failure.

9. When the cold wave is moving southward and at 7 a. m. is well established in the southern plains and threatens the Texas coast, the mean of the 7 a. m. temperatures at Santa Fe and Oklahoma will be 17° lower than Galveston's minimum of the next morning. When not well established in the southern plains at 7 a. m. the cold wave will not arrive at Galveston in 24 hours unless the pressure gradients are abnormally steep and the impending cold wave exceptionally severe.

10. When exceptionally violent the cold wave may reach the Texas coast from Oklahoma in less than 24 hours, in which case the temperature at Oklahoma is not a reliable index. This condition is characterized by excessive temperature differences between North Platte and Oklahoma.

11. When there is a depression in the southern Rockies and the pressure at Helena, Mont., is 0.60 inch or more above that at New Orleans, a cold wave is threatened. Its violence increases with the gradient.

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